# EFFECT OF VEHICLE AND CRASH FACTORS ON OLDER OCCUPANT INJURY

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## ABSTRACT

The 2000 United States Census counted 35 million residents aged 65 years old or older. Projections indicate that this number will increase to 63 million by 2025. This increase is important for those concerned about vehicle safety because older drivers and passengers are vulnerable road users. Much of the previous research concentrates on the role of the aging process on crash involvement among older drivers, but these lines of questioning overlook the fact that vehicle and crash factors may be a significant part of why older occupants suffer higher injury and fatality rates.

This paper demonstrates the role that vehicle and crash factors play in explaining differences in injuries across age groups. Important vehicle and crash characteristics include the number of vehicles involved, the body type of the occupant's vehicle as well as body type of the other vehicle in two vehicle crashes, the initial point of impact, and the total change in velocity experienced by the occupants.

The types of vehicles driven by the coming older generation, together with higher average speeds and the recent shifts in vehicle mix on the road, are cause for even greater concern for the protection of older occupants. The results demonstrate that variation in the types of crashes and vehicles across age groups is important for explaining injuries. Examination of these factors provides information for consideration of possible regulatory changes needed to protect older drivers and passengers. The results also may be informative to automotive manufacturers who are considering modifications to accommodate older occupants.

## INTRODUCTION

According to a recent study by the United States Census Bureau, the world's population of age 65 or older grew by more than 795,000 people each month during 2000. This rate is expected to increase so that the older population will grow by more than 847,000 a month during 2010. By 2030 more than 60 nations are expected to have more than 2 million people aged 65 or older, which is twice the number of nations reaching this benchmark in 2000 [1]. In the United States alone the number of people 65 and older was 35 million in 2000. By 2030 this number is expected to double to over 70 million [2].

A significant number of the older population will continue to drive, and those who do not are likely to be vehicle occupants. This projected increase in the number of older road users has spurred public debate as well as scholarly research. When examining US vehicle occupant fatality rates per 100,000 population, people aged 65 to 74 have rates similar to those aged 35 to 44. Although the fatality rate increases for those 75 and older, it is still below the rate for people aged 16 to 24. Occupant injury rates per 100,000 population appear to diminish with age. For people over 75 the rate is about half of its value for those 35 to 44 and one-quarter for people aged 16 to 24 [3].

While these numbers are informative, many traffic safety researchers argue that these statistics may be misleading because they do not account for exposure. In other words, older people may have a lower fatality and injury rate per person because they do not travel as often or as far as younger people. One frequently used approach to control for differences in exposure is to examine driver fatality rates per 100 million vehicle miles traveled (VMT). This analysis produces a U-shaped curve where the highest fatality rates are for the youngest and oldest drivers [4]. However, this approach does not fully capture exposure either because it focuses on drivers rather than all occupants. Previous research has shown that people over 65, especially women, have a higher proportion of miles traveled as non-drivers than all younger adults except teenagers [5].

Even though a significant amount of vehicle travel by older occupants occurs as a passenger, the existing literature mainly focuses on the fatality risk of older drivers. One line of research aims to explain why the fatality rate per mile is higher for older drivers. Two possible explanations are higher crash involvement and higher fragility. Higher crash involvement means greater potential for injury caused by a crash, and higher fragility means greater chance of injury given that a crash occurred. While crash involvement per VMT does increase appreciably after age 70, research indicates that fragility is a more important explanation [6,7]. This conclusion fits with research showing that older occupants have higher fatality risk from similar impacts than younger occupants [8]. It also is supported by studies from Canada and the United States showing that age is an important predictor of older driver injury severity even when controlling for vehicle and crash characteristics [9,10]. A related analysis demonstrated that fatal crash rates per 100,000 population still differ by age after controlling for urban versus rural through population density [11]. Fatality rates, along with assumptions about changes in population, licensure rates, and annual miles traveled, have also been used to make future projections. One such study claims that by 2030 drivers 65 and older will account for 25 percent of driver fatalities compared to the 14 percent in 1999 [6].

Another set of studies compares crash scenarios across age groups. This type of analysis helps provide information regarding how crash situations involving older drivers differ from those involving younger drivers and offers suggestions for improving safety for older drivers. Overall, older drivers are a relatively safe group. They are less likely to have crashes involving alcohol or high speeds than younger drivers [12]. However, studies of crashes in both Finland and the United States have shown that older drivers are over-represented in crashes at intersections, particularly in collisions with crossing vehicles, and are more likely to be at fault in these crashes [12,13]. A close examination of intersection crashes revealed that uncontrolled and stop-sign controlled intersections represent the highest fatality risk for older drivers relative to younger drivers [14]. Research also has found that older drivers are more likely to be involved in collisions while making turns, particularly left-hand turns [12,15]. The most frequent policy recommendation from this line of research is light-controlled intersections with protected left-turn signals.

While all of these previous studies help us to understand the interaction between age and crash factors, there is more that can be learned. The focus on drivers, for example, tends to overlook the frequency with which older people, especially women, are vehicle occupants. Furthermore, the role of vehicle and crash characteristics can be expanded to account for other potentially important factors such as the types of vehicles driven by older drivers, differences in the point of impact in a crash, and the vehicle mix on the road.

## METHODS

This paper uses a variety of methods and data sets to understand the relationship between age and important crash characteristics. The analysis seeks to provide information on the factors that influence vehicle safety outcomes for the oldest segment of the population, and their importance. They cover the issues of exposure, crash involvement, and severity outcomes.

### Exposure - Travel

The first approach is to examine differences in exposure across age groups and time using the preliminary release of the 2001 National Household Travel Survey (NHTS) and the most recent version of the 1995 Nationwide Personal Transportation Survey (NPTS). Over 26,000 households reported their travel behavior via telephone interview from April 2001 to May 2002 for the 2001 NHTS. The 1995 NPTS includes reported travel behavior from over 42,000 households. The travel data presented are for day trips, defined as “any time the respondent went from one address to another” in a designated 24-hour period, completed in privately owned motor vehicles [16]. Only day trips are included for comparison because the full set of data for the 2001 survey was not available at the time of preparation for this paper.

The private vehicles category in these surveys includes cars, vans, sport utility vehicles, pickup trucks, motorcycles, large trucks, and motor homes, but it does not differentiate between light and large vehicles using vehicle weight. These surveys also contain weighting factors to produce national travel estimates. The age groups used are 25 to 44, 45 to 64, 65 to 74, and 75 and older. The decision to focus on occupants 25 and older is to make the comparison groups more appropriate by excluding the most inexperienced drivers. Older occupants also are split into two categories (65-74 and 75+) to distinguish between the younger old and the rapidly growing group of the oldest occupants. This approach will provide evidence of how exposure patterns, measured by estimated annual miles traveled, are affected by age and temporal trends.

### Exposure - Crash Involvement

The second approach is to examine whether crash involvement patterns for occupants differ across age groups. For crash involvement, we rely on the five most recent years of the National Automotive Sampling System - General Estimates System (NASS-GES or GES 1997 to 2001). GES is based on a nationally representative sample of about 57,000 police-reported crashes per year. GES crashes must have a police accident report, which is the basis for all coded values, must “involve at least one motor vehicle traveling on a trafficway,” and “must result in property damage, injury, or death" [3]. GES also contains a weighting factor to produce annual estimates of the characteristics of police-reported crashes. This approach will enable us to address the effect of crash exposure for explaining differences in injury patterns across age groups.

**Crash Outcomes - Fatalities and Injuries**

The third approach is to examine the variation across age groups for the vehicle and crash characteristics that produce fatal and serious injuries. For fatal injuries, we rely on the most recent five years of the Fatality Analysis Reporting System (FARS 1997 to 2001). FARS is a census of all crashes involving a motor vehicle on a public roadway that resulted in at least one fatality within 30 days of the incident. While FARS contains information on non-motorist fatalities, this analysis focuses on vehicle occupant deaths. Because FARS is a census, the results reflect national totals and do not require a weighting factor.

For non-fatal injuries, we return to the GES. Injury severity in GES is measured on a police-reported injury scale with values of none, possible, non-incapacitating, incapacitating, and fatal. While police-reported injury severity serves some purposes, there are potential measurement issues because police-reported severity may not reflect real injuries, especially at lower levels of severity. Police-reported severity is likely to be more accurate for incapacitating and fatal injuries. Our GES analysis of serious injuries focuses on incapacitating injuries because they should accurately represent the most serious non-fatal injuries and does not examine fatal injuries because they are covered by FARS. It should be noted, however, that incapacitating injuries from police-reported injury severity are not necessarily the same as serious injuries from the Abbreviated Injury Scale (AIS) discussed in the next section, which is not available in GES. Because GES is a sample of crashes, we used the weighting factor to produce national estimates. Our analysis of fatal and incapacitating injuries by age and crash scenario uses the age groups previously discussed.

**Crash Outcomes - Modeling Injury Severity**

The fourth method involves predicting the degree of injury severity resulting from change in velocity (delta-V), age, and other important factors. This analysis requires the use of the National Automotive Sampling System - Crashworthiness Data System (NASS-CDS 1997 to 2001). NASS-CDS is a probability sample of police-reported crashes involving at least one towed light vehicle and either property damage or personal injury. Selected crashes are investigated by a NASS team. The focus on more severe crashes and the detailed scrutiny of crash sites, vehicles, and medical records leads to the investigation of about 4,000 crashes per year. While the sample is smaller, NASS-CDS contains two important variables for predicting injury severity that are not included in GES. NASS-CDS measures injury severity using the Abbreviated Injury Scale (AIS) and contains a variable for the maximum known AIS for towed vehicle occupants as well as those in vehicles with air bag deployment. The NASS-CDS also contains the total change in velocity (total delta-V) for investigated vehicles, which is often strongly correlated to occupant injury severity.

The technique used to predict the effects of age, delta-V, and other factors on injury severity is ordered probit. Ordered probit is an extension of the more common dichotomous probit and closely related logit analysis [17]. In dichotomous probit, the variable that the researcher is trying to explain takes two possible values (such as yes or no, success or failure, etc.). The explanatory variables are then used to estimate the unobserved probability of an observation taking a particular value (such as the probability of a respondent answering yes). Because the approach is multivariate, a researcher can isolate the effect of one variable on the estimated probability while controlling for other explanatory variables.

Ordered probit is an extension used when the variable that the researcher wants to explain takes more than two ordered categorical values. Consider the case of the effect of age on injury severity. If injury severity were measured with two values such as no injury versus injury, then dichotomous probit would produce the estimated effect of age on the probability of an occupant injury. Now suppose that injury severity is measured by the maximum injury on a scale such as none, minor, moderate, serious, and severe. These five categories have order because they represent increasing injury severity, and ordered probit would be an appropriate tool for analyzing the effect of age. Ordered probit would produce estimates of the effect of age on the probability of an occupant suffering a maximum injury of each severity level. Thus ordered probit would produce five estimated probabilities, one for each severity level, and these estimated probabilities would sum to one because they cover all possible outcomes. It is highly unlikely that age would be the only factor affecting injury severity, and our analysis contains other important control variables, such as delta-V, to isolate the effect of age on injury severity. We also use an appropriate weighting factor to reflect national estimates of the distribution of crash scenarios, occupant characteristics, and injuries.

## RESULTS

The results are divided into four sections. The first section explores how exposure, in terms of miles traveled and crash scenarios, differs by age groups and how it has changed over time. The second section examines how fatal injuries vary by age and crash characteristics. The third section presents incapacitating injuries in a similar fashion. The fourth section demonstrates the relationship between the severity of injury, the age of the occupant, and the change in velocity (delta-V) in various crash modes.

### Exposure

We measure exposure both in terms of miles traveled and crash involvement. The results for miles traveled are based on early results from the 2001 NHTS, in which over 26,000 households reported their travel behavior via telephone interview. As previously discussed, the preliminary release includes information on travel day trips, defined as "any time the respondent went from one address to another" in a designated 24-hour period, by various transportation modes including private motor vehicles. Travel day trips aim to capture everyday travel patterns in the United States, and the designated days assigned to respondents cover an entire year. Using a weighting factor, the survey responses can be used to produce national travel estimates. These estimates are then used by researchers to compute the total number of miles traveled as well as the number of miles per person. Table 1 provides an overview of the changes in these statistics from 1995 to 2001. Table 2 presents the percentage distribution of the miles traveled by gender, driver status, and vehicle type across the various age groups.

While person miles per person for day trips increased for all age groups, there have been striking differences - from less than 1% for 25 to 44 year olds to 20% for the 75 and older population. The differences in total day trip miles are even more dramatic, with total miles traveled by the oldest Americans increasing by over 50%. The difference between the increase in total miles traveled and in miles traveled per person reflects that changes are occurring both in the size of older population as well as in their behavior. These results are a more inclusive picture of changes in exposure than previous work based exclusively on driving behavior [6,18]. However, the results are similar in that they reflect the importance of the increasing population size on future older driver target population estimates.

**Table 1.**
**Changes in Total Person Miles Traveled in Privately Owned Vehicles by Age (1995 NPTS and 2001 NHTS Day Trips)**

| Age | 1995 | 2001 | Percent Change |
|---|---|---|---|
| Total Person Miles (billions) | | | |
| 25-44 | 1,352 | 1,360 | 1% |
| 45-64 | 764 | 931 | 22% |
| 65-74 | 191 | 211 | 10% |
| 75+ | 66 | 100 | 51% |
| | | | |
| Person Miles per Person | | | |
| 25-44 | 15,780 | 15,856 | <1% |
| 45-64 | 14,854 | 15,312 | 3% |
| 65-74 | 9,796 | 11,312 | 15% |
| 75+ | 5,659 | 6,772 | 20% |

Note: Sample sizes for youngest to oldest age group:
1995 Person sample
unweighted: 32,533; 23,227; 8,014; 4,677
weighted (in millions): 85.7; 51.4; 19.5; 11.7
2000 Person Sample
unweighted: 16,080; 16,533; 5,313; 4,139
weighted (millions): 85.8; 60.8; 18.7; 14.8

**Table 2.**
**Distribution of Person Miles Traveled by Age and Other Factors (1995 NPTS and 2001 NHTS Day Trips)**

| | *25-44* | *45-64* | *65-74* | *75+* |
|---|---|---|---|---|
| 1995: Gender/Driver | | | | |
| Male: Driver | 48 | 50 | 46 | 36 |
| Male: Passenger | 7 | 7 | 8 | 13 |
| *Male Subtotal* | *55* | *57* | *54* | *49* |
| Female: Driver | 31 | 26 | 24 | 23 |
| Female: Passenger | 14 | 17 | 22 | 28 |
| *Female Subtotal* | *45* | *43* | *46* | *51* |
| *Total* | *100%* | *100%* | *100%* | *100%* |
| | | | | |
| 2001: Gender/Driver | | | | |
| Male: Driver | 48 | 50 | 47 | 41 |
| Male: Passenger | 6 | 6 | 6 | 10 |
| *Male Subtotal* | *54* | *56* | *53* | *51* |
| Female: Driver | 31 | 28 | 22 | 21 |
| Female: Passenger | 14 | 16 | 26 | 28 |
| *Female Subtotal* | *56* | *54* | *47* | *49* |
| *Total* | *100%* | *100%* | *100%* | *100%* |

| | | | | |
|---|---|---|---|---|
| 1995:Vehicle Mode | | | | |
| Car | 59 | 62 | 73 | 84 |
| Van | 11 | 10 | 8 | 4 |
| Utility Vehicle | 9 | 8 | 4 | 3 |
| Pick-up | 16 | 16 | 14 | 7 |
| Other | 4 | 4 | 1 | 1 |
| *Total* | *100%* | *100%* | *100%* | *100%* |
| 2001:Vehicle Mode | | | | |
| Car | 52 | 55 | 71 | 77 |
| Van | 13 | 11 | 9 | 10 |
| Utility Vehicle | 16 | 13 | 5 | 3 |
| Pick-up | 17 | 18 | 14 | 7 |
| Other | 3 | 3 | 1 | 3 |
| *Total* | *100%* | *100%* | *100%* | *100%* |

Note: Person sample sizes same as Table 1.

There was little change between 1995 and 2001 in the driver versus passenger shares of total person miles traveled by age groups except for some shift from miles by male passengers to male drivers in the 75 and older age group. If this pattern continues, it suggests a growing need for crash avoidance countermeasures for older drivers. However, on the crashworthiness side, there has been some shift in miles traveled by the oldest population from passenger cars into vans. This shift works in a positive direction with regard to vehicle compatibility issues because vans have a lower vulnerability metric, defined as deaths in struck vehicles per 1000 police reported crashes, than passenger cars in side impact crashes [19].

The changes indicated by these early results from the 2001 NHTS survey provide evidence that mobility for older people of current and future generations of older people (i.e. baby boomers and beyond) may be significantly different than for previous generations, which underscores the need for increased attention to older occupant safety.

Another common way of addressing exposure is to examine driver involvement in crashes by age. Crash involvement is computed as the number of drivers in a certain age category per 100,000 licensed drivers. These numbers are contained in Table 3.

**Table 3.**
**Exposure Measured by Driver Crash Involvement and Annual Miles Traveled (2001)**

| Driver Age | All Crashes per 100,000 Licensed Drivers | PDO Crashes per 100,000 Licensed Drivers | Injury Crashes per 100,000 Licensed Drivers | Fatal Crashes per 100,000 Licensed Drivers | Annual person miles per person [day trips] |
|---|---|---|---|---|---|
| 25-44 | 5880 | 3923 | 1928 | 29.30 | 15,856 |
| 45-64 | 4248 | 2874 | 1352 | 21.52 | 15,312 |
| 65-74 | 3170 | 2094 | 1056 | 19.75 | 11,312 |
| 75+ | 2928 | 1844 | 1056 | 28.11 | 5,659 |
| Change from older group | | | | | |
| 45-64 | 27.8%↓ | 26.7%↓ | 29.9%↓ | 26.6%↓ | 3.4%↓ |
| 65-74 | 25.4%↓ | 27.1%↓ | 21.8%↓ | 8.2%↓ | 26.1%↓ |
| 75+ | 7.6%↓ | 12.0%↓ | 0.0%↓ | 42.4%↑ | 40.1%↓ |

Note: Licensed drivers from Federal Highway Administration [20], PDO and injury crashes from GES 2001, fatal crashes from FARS 2001, and person miles from NHTS 2001.

While crash involvement rates per licensed driver in all crashes are lower for the oldest drivers than for any other age group, they do not fall as dramatically as driver exposure, based on annual person miles per person. This comparison is incomplete, due to missing data for longer trips, however, Table 3 indicates that there are some crash incidence factors, as well as "survivability" factors, at work. While driver involvement rates in Property Damage Only (PDO) and injury-producing crashes also follow this consistent downward trend by age, the driver involvement rate in fatal crashes for the oldest age group is over 30 percent higher than the next oldest group. Along with the results for occupant crash involvement by severity (see next section), this speaks to the strong influence of higher crash consequences for the oldest population group.

Another way to address age differences in exposure is to analyze the crash scenario to which an occupant is exposed given a crash. This analysis uses the GES estimates of all police-reported crashes for the most recent five years (1997-2001). Table 3 summarizes these results. The results are presented as percentages within each age category to facilitate comparison across the columns. Light vehicles are defined as vehicles having a Gross Vehicle Weight Rating (GVWR) of less than 10,000 pounds and include passenger cars, utility vehicles, light vans, and most pickup trucks. Large vehicles have a GVWR greater than 10,000 pounds and include trucks, buses, and large vans. The table focuses on light vehicle occupants crashes but also contains the percentage for other vehicle types.

Table 4 demonstrates that older occupants involved in a crash are more likely to be in a light vehicle than a large vehicle. Even more telling, older occupants are much more likely to be in a car than an LTV. This result agrees with exposure by vehicle type based on miles traveled from the NHTS and NPTS. The results also indicate that older occupants have a higher exposure to side impact crashes, particularly side impacts where they are in the struck vehicle, than younger occupants.

**Table 4.**
**Occupants in Police-Reported Crashes by Vehicle Type and Crash Mode (GES 1997-2001)**

| *Type of Occupant and Crash Mode* | *Percent of All Crash Occupants By Age Group* | | | |
|---|---|---|---|---|
| | 25-44 | 45-64 | 65-74 | 75+ |
| **Light Vehicle Occupants** | | | | |
| Single Vehicle Crash | | | | |
| Rollover | 2 | 1 | 1 | 1 |
| Fixed Object Collision | 5 | 6 | 6 | 6 |
| Other and Unknowns | 6 | 4 | 4 | 4 |
| *Single Vehicle Subtotal* | *13* | *11* | *10* | *11* |
| Two Vehicle Crash | | | | |
| Rollover Vehicle | <1 | <1 | <1 | <1 |
| Two Light Vehicles | | | | |
| Frontal | 2 | 2 | 3 | 3 |
| Side: Struck | 11 | 12 | 17 | 20 |
| Side: Striking | 12 | 11 | 14 | 16 |
| Rear-end | 26 | 25 | 23 | 18 |
| Other and Unknowns | 12 | 12 | 14 | 14 |
| With Large Vehicle | 2 | 3 | 3 | 3 |
| With Other Type | 2 | 2 | 2 | 3 |
| *Two Vehicle Subtotal* | *68* | *69* | *75* | *78* |
| Three or More Vehicle Crash | 11 | 12 | 11 | 9 |
| *Car Subtotal* | *57* | *57* | *70* | *82* |
| *LTV Subtotal* | *35* | *35* | *27* | *16* |
| *Light Vehicle Subtotal* | *93* | *92* | *97* | *98* |
| **Large Vehicle Occupants** | 4 | 5 | 1 | <1 |
| **Motorcycle Occupants** | 1 | 1 | <1 | <1 |
| **Other and Unknown** | 2 | 3 | 2 | 2 |

Note: Sample sizes for youngest to oldest age group: Unweighted: 247,158; 121,541; 25,834; 18,145 Weighted (in millions): 27.2; 13.4; 3.1; 2.2

These findings further confirm the continued over-involvement of older occupants, particularly drivers, in side impact collisions at intersections and while making turns. Interestingly, exposure to rear-end crashes appears to diminish with age. This change would work against lower fatality rates for older occupants because rear-end crashes rarely produce fatalities.

**Crash Outcomes - Fatal Injuries**

This section examines whether fatality patterns differ across age groups. Table 5 contains the distribution of fatal injuries to vehicle occupants recorded in FARS from 1997 to 2001 by age and by occupant type and crash mode.

**Table 5.**
**Occupant Fatalities by Age and Crash Mode (FARS: 1997-2001)**

| *Type of Occupant and Crash Mode* | *Percent of All Occupant Fatalities By Age Group* | | | |
|---|---|---|---|---|
| | 25-44 | 45-64 | 65-74 | 75+ |
| **Light Vehicle Occupants** | | | | |
| Single Vehicle Crash | | | | |
| Rollover | 25 | 19 | 12 | 7 |
| Fixed Object Collision | 17 | 14 | 14 | 13 |
| Other and Unknowns | 3 | 3 | 2 | 2 |
| *Single Vehicle Subtotal* | *45* | *36* | *29* | *22* |
| Two Vehicle Crash | | | | |
| Rollover Vehicle | 4 | 5 | 4 | 3 |
| Two Light Vehicles | | | | |
| Frontal | 10 | 13 | 16 | 17 |
| Side: Struck | 7 | 10 | 18 | 27 |
| Side: Striking | 1 | 2 | 2 | 3 |
| Other and Unknowns | 2 | 2 | 3 | 4 |
| With Large Vehicle | 7 | 8 | 11 | 11 |
| With Other Type | 1 | 1 | 1 | 1 |
| *Two Vehicle Subtotal* | *33* | *41* | *55* | *65* |
| Three or More Vehicle Crash | 7 | 9 | 11 | 11 |
| *Light Vehicle Subtotal* | *84* | *86* | *95* | *98* |
| **Large Vehicle Occupants** | 3 | 4 | 1 | <1 |
| **Motorcycle Occupants** | 12 | 8 | 2 | <1 |
| **Other and Unknown** | 1 | 1 | 1 | 1 |

Note: Sample sizes for youngest to oldest age group: 59,369; 34,234; 12,592; 16,753

As expected, there is a strong relationship between age and occupant type. For the 25 to 44 age group, 84 percent of the vehicle fatalities occurred in light vehicles. This number rises to 98 percent for the 75 and over age group. The higher percentage of light vehicle fatalities for older occupants reflects the substantial drop in the proportion of motorcycle fatalities and, to a lesser extent, large vehicle occupant fatalities after 65.

Age is also strongly related to the crash mode for light vehicle occupant fatalities. The proportion of fatalities in single vehicle crashes drops from 45 percent for the youngest group to 22 percent for the oldest group. When examining only light vehicle fatalities, the drop is from over one-half for the youngest group to under one-quarter for oldest group. This drop occurs mainly because single-vehicle rollovers appear to be a young person's crash. This crash mode accounts for one-quarter of the vehicle occupant fatalities for those aged 25 to 44. By comparison, it only accounts for 7 percent for those 75 and older. The proportion of fatalities occurring in single-vehicle fixed object collisions also diminishes with age, but the drop is not as substantial as for rollovers.

As the role of single-vehicle crashes in explaining fatalities decreases with age, the importance of crashes involving two or more vehicles increases. Two vehicle crashes account for one-third of the fatalities for the youngest group and almost two-thirds for the oldest. This increase is reflected in the large proportions of older occupant fatalities in light vehicles stuck in the side by the front of another light vehicle and in frontal crashes involving two light vehicles. Where single-vehicle rollovers can be described as a young person's crash, side impact appears to be an old person's crash. Fatalities occurring in light vehicles struck in the side account for over one-quarter of the total occupant fatalities for those 75 and older but only 7 percent for those 25 to 44. The proportion of fatalities from a frontal crash involving two light vehicles also increases with age from 10 percent for the youngest group to 17 percent for the oldest. The proportion of light vehicle fatalities occurring in crashes involving a large vehicle or three or more vehicles also increases with age.

Table 5 demonstrated that light vehicle occupant fatalities in two vehicle crashes accounted for a majority of the fatalities for those 65 and older. Furthermore, one reason that side impact may be particularly important for explaining older occupant fatalities may be that the type of light vehicle differs by occupant age. Using the 2001 FARS, the ratio of driver fatalities in striking versus struck vehicles in side impact collisions is 1 to 8 for a car striking another car but 1 to 29 for a light truck or van (LTV) striking a car.

**Table 6.**
**Light Vehicle Occupant Fatalities**
**in Two-Vehicle Non-Rollover Crashes**
**by Age and Crash Mode (FARS 1997-2001)**

| *Type of Light Vehicle Occupant and Crash Mode* | *Percent of All Occupant Fatalities by Age Group* | | | |
|---|---|---|---|---|
| | *25-44* | *45-64* | *65-74* | *75+* |
| **Car Occupants** | | | | |
| Frontal with Car | 12 | 12 | 13 | 12 |
| Side Struck by Car | 8 | 9 | 12 | 16 |
| Striking Side of Car | 1 | 2 | 1 | 2 |
| All Other with Car | 2 | 2 | 2 | 2 |
| *Car with Car Subtotal* | *24* | *25* | *28* | *33* |
| Frontal with LTV | 14 | 12 | 12 | 10 |
| Side Struck by LTV | 13 | 15 | 18 | 23 |
| Striking Side of LTV | 1 | 1 | 2 | 2 |
| All Other with LTV | 3 | 2 | 3 | 2 |
| *Car with LTV Subtotal* | *31* | *30* | *35* | *37* |
| With Large Truck | 16 | 14 | 14 | 13 |
| With Other Body Type | 1 | 1 | 2 | 2 |
| *Car Occupant Subtotal* | *72* | *69* | *78* | *85* |
| **LTV Occupants** | | | | |
| Frontal with Car | 3 | 4 | 3 | 2 |
| Side Struck by Car | 1 | 2 | 2 | 1 |
| Striking Side of Car | 1 | 1 | 1 | <1 |
| All Other with Car | 1 | 1 | 1 | <1 |
| *LTV with Car Subtotal* | *5* | *7* | *5* | *4* |
| Frontal with LTV | 7 | 7 | 4 | 2 |
| Side Struck by LTV | 3 | 3 | 3 | 3 |
| Striking Side of LTV | 1 | 1 | 1 | <1 |
| All Other with LTV | 1 | 1 | 1 | 1 |
| *LTV with LTV Subtotal* | *11* | *13* | *9* | *6* |
| With Large Truck | 10 | 10 | 7 | 4 |
| With Other Body Type | 1 | 1 | 1 | <1 |
| *LTV Occupant Subtotal* | *27* | *30* | *22* | *14* |

Note: Sample sizes for youngest to oldest age group: 16,956; 12,432; 6,461; 10,400

Given the importance of light vehicles overall and of the distinction between passenger car and LTV occupants, Table 6 provides more detailed information regarding light vehicle fatalities in non-rollover crashes. For all age groups, car occupant fatalities outnumber LTV occupant fatalities. However, the proportion increases from 69 percent for the 45 to 64 group to 85 percent for the 75 and older group. Correspondingly, the proportion of LTV occupant fatalities decreases with age in almost every crash scenario. The other significant difference occurs in the proportion of fatalities from side impact. From the youngest to the oldest age group, the proportion of fatalities involving a car striking a car in the side increases by 8 percent and those involving an LTV striking a car in the side increases by 10 percent. For those 75 and older, almost 1 in 4 occupant fatalities occur when an LTV strikes the side of a car.

**Crash Outcomes - Incapacitating Injuries**

This section examines incapacitating injuries in a manner similar to the previous section. As discussed in the methods section, this analysis uses police-reported incapacitating injuries for the five most recent years of GES (1997 to 2001). Table 7 presents the results for all vehicle occupants, and Table 8 presents the results for light vehicle occupants in two-vehicle non-rollover crashes.

For the most part, the results in Table 7 are similar to those for fatalities. The proportion of incapacitating injuries from single-vehicle crashes diminishes with age. There appears to be an increase in incapacitating injuries from fixed object collisions in the oldest age group, but more work needs to be done to determine if this result is substantive or mainly sampling error. The likelihood of an incapacitating injury resulting from a two light vehicle frontal crash is almost the same across age groups. However, the likelihood of an incapacitating injury for light vehicle occupants struck in the side increases substantially with age.

Table 8 presents a closer look at incapacitating injuries for light vehicle occupants involved in two-vehicle non-rollover crashes. Similar to the case for fatalities, there is a substantial increase in the proportion of light vehicle occupant incapacitating injuries in cars struck by other cars and LTVs as occupant age increases. Another similarity between Tables 6 and 8 is that car and LTV subtotals reflect the exposure data where older occupants are more likely to travel in cars than LTVs. Finally, the proportion of light vehicle collisions with large trucks is lower for all age groups when compared to fatalities.

**Table 7.**
**Vehicle Occupants with Incapacitating Injuries by Age and Crash Mode (weighted GES 1997-2001)**

| *Type of Occupant and Crash Mode* | *Percent of All Incapacitating Injuries By Age Group* | | | |
|---|---|---|---|---|
| | 25-44 | 45-64 | 65-74 | 75+ |
| **Light Vehicle Occupants** | | | | |
| Single Vehicle Crash | | | | |
| Rollover | 12 | 7 | 6 | 3 |
| Fixed Object Collision | 15 | 11 | 9 | 14 |
| Other and Unknowns | 2 | 1 | 2 | 1 |
| *Single Vehicle Subtotal* | *28* | *20* | *17* | *18* |
| Two Vehicle Crash | | | | |
| Rollover Vehicle | 3 | 2 | 3 | 2 |
| Two Light Vehicles | | | | |
| Frontal | 7 | 7 | 8 | 7 |
| Side: Struck | 14 | 16 | 20 | 28 |
| Side: Striking | 11 | 12 | 14 | 12 |
| Other and Unknowns | 14 | 16 | 16 | 14 |
| With Large Vehicle | 3 | 4 | 4 | 3 |
| With Other Type | 1 | 1 | 1 | 1 |
| *Two Vehicle Subtotal* | *52* | *58* | *66* | *67* |
| Three or More Vehicle Crash | 10 | 13 | 14 | 13 |
| *Light Vehicle Subtotal* | *91* | *90* | *97* | *99* |
| **Large Vehicle Occupants** | 2 | 2 | <1 | <1 |
| **Motorcycle Occupants** | 6 | 6 | 1 | <1 |
| **Other and Unknown** | 1 | 2 | 1 | 1 |

Note: Sample sizes for youngest to oldest age group:
Unweighted: 9,968; 5,158; 1,163; 1,038
Weighted: 639,862; 322,811; 82,106; 72,890

**Table 8.**
**Light Vehicle Occupants with Incapacitating Injuries in Two-Vehicle Non-Rollover Crashes by Age and Crash Mode (weighted GES 1997-2001)**

| *Type of Light Vehicle Occupant and Crash Mode* | *Percent of All Incapacitating Injuries by Age Group* | | | |
|---|---|---|---|---|
| | *25-44* | *45-64* | *65-74* | *75+* |
| **Car Occupants** | | | | |
| Frontal with Car | 6 | 6 | 6 | 6 |
| Side Struck by Car | 13 | 13 | 17 | 23 |
| Striking Side of Car | 11 | 9 | 13 | 9 |
| All Other with Car | 12 | 11 | 11 | 8 |
| *Car with Car Subtotal* | *41* | *38* | *47* | *47* |
| Frontal with LTV | 3 | 3 | 3 | 3 |
| Side Struck by LTV | 9 | 9 | 12 | 15 |
| Striking Side of LTV | 5 | 5 | 5 | 5 |
| All Other with LTV | 9 | 10 | 9 | 9 |
| *Car with LTV Subtotal* | *26* | *27* | *29* | *32* |
| With Large Truck | 5 | 5 | 4 | 3 |
| With Other Body Type | 1 | 2 | <1 | 2 |
| *Car Occupant Subtotal* | *73* | *72* | *81* | *84* |
| **LTV Occupants** | | | | |
| Frontal with Car | 2 | 2 | 3 | 1 |
| Side Struck by Car | 3 | 4 | 2 | 4 |
| Striking Side of Car | 4 | 4 | 2 | 1 |
| All Other with Car | 5 | 4 | 3 | 2 |
| *LTV with Car Subtotal* | *14* | *14* | *10* | *8* |
| Frontal with LTV | 2 | 2 | 1 | 1 |
| Side Struck by LTV | 3 | 3 | 1 | 1 |
| Striking Side of LTV | 3 | 3 | 3 | 3 |
| All Other with LTV | 3 | 4 | 2 | 2 |
| *LTV with LTV Subtotal* | *10* | *11* | *7* | *6* |
| With Large Truck | 2 | 2 | 1 | 1 |
| With Other Body Type | <1 | 1 | 1 | <1 |
| *LTV Occupant Subtotal* | *27* | *28* | *19* | *16* |

Note: Sample sizes for youngest to oldest age group:
Unweighted: 4,807; 2,693; 719; 692
Weighted: 317,512; 178,074; 51,775; 47,843

**Crash Outcomes - Severity of Injury**

This section uses the ordered probit method, discussed in the methods section, to estimate the effect of delta-V, age, gender, belt use, and the type of other light vehicle on the probability of a particular maximum AIS for each car occupant. The data are weighted by the national inflation factor, which has been normalized to reflect the actual number of cases. While this approach does not capture all of the complexity of the NASS multistage sampling design when computing standard errors, it does provide a good first approximation of the hypothesized relationships. The restriction to car occupants makes modeling simpler because it restricts the vehicle type combinations and reflects the fact that few older occupants travel in LTVs. Given the exposure data, these results will reflect the injury risk faced by most older occupants.

Two particular occupant crash scenarios are examined using data from the 1997 to 2001 NASS-CDS: two-vehicle frontal crashes involving a car and another light vehicle, and nearside impact crashes where the front of the striking light vehicle hits the side of a car on which the occupant is seated. Belt use was dropped from the nearside impact analysis because it did not achieve statistical significance in the expected direction. This may reflect the fact that safety belts are more effective in frontal than side impacts. A variable attempting to capture problems with vehicle compatibility was also tried by including an indicator variable when the other vehicle was an LTV. This measure is included in the model of nearside injury severity because it achieved statistical significance in the expect direction, but it was dropped from the analysis of frontal crashes. Finally, the handful of cases with values of delta-V greater than 100 kilometers per hour were dropped to prevent overly influential outliers.

Tables 9 and 10 summarize the effect of age at various levels of delta-V on the predicted probability of each injury severity. The results in Table 9 also control for gender differences (women are more likely to have a higher maximum AIS than men) and safety belt use (occupants not using a safety belt are more likely to have higher maximum AIS than those who do use a safety belt.) The results in Table 10 control for gender differences and whether the other vehicle is an LTV. The middle two sets of results in Table 10 further illustrate that car occupants struck by LTVs are more likely to have a higher maximum AIS than car occupants struck by another car. The complete results, including probit coefficients and statistical significance, are contained in the Appendix.

**Table 9.**
**Predicted Probabilities of Maximum Injury Severity to Car Occupants by Age and Delta-V in Non-Rollover Two-Light Vehicle Frontal Crashes (NASS-CDS 1997 to 2001)**

| Probability of Maximum AIS | 30 year old | 55 year old | 70 year old |
|---|---|---|---|
| | (prediction for belted female) | | |
| Total Delta-V of 20 KMPH | | | |
| None (0) | 0.46 | 0.33 | 0.22 |
| Minor (1) | 0.48 | 0.55 | 0.58 |
| Moderate (2) | 0.05 | 0.08 | 0.11 |
| Serious (3) | 0.02 | 0.03 | 0.06 |
| Severe (4+) | 0.00 | 0.01 | 0.02 |
| Total Delta-V of 35 KMPH | | | |
| None (0) | 0.18 | 0.13 | 0.10 |
| Minor (1) | 0.58 | 0.56 | 0.53 |
| Moderate (2) | 0.13 | 0.16 | 0.18 |
| Serious (3) | 0.08 | 0.10 | 0.13 |
| Severe (4+) | 0.03 | 0.04 | 0.06 |
| Total Delta-V of 50 KMPH | | | |
| None (0) | 0.04 | 0.04 | 0.03 |
| Minor (1) | 0.42 | 0.40 | 0.38 |
| Moderate (2) | 0.21 | 0.21 | 0.21 |
| Serious (3) | 0.20 | 0.21 | 0.22 |
| Severe (4+) | 0.13 | 0.14 | 0.16 |

Tables 9 and 10 present probabilities of injury levels for particular scenarios. To illustrate interpretation consider the top sub-table within Table 9. The predicted probabilities are for a 30 year-old belted female car occupant in a frontal crash with another light vehicle with a total delta-V of 20 KMPH. As one moves across the columns, the only assumption that changes is the age of the car occupant. As one moves down the column to the second sub-table, the only assumption that changes is that total delta-V increases to 35 KMPH. One could construct other tables for males or unbelted occupants, but the effect of age would stay essentially the same because the model explicitly controls for these two factors. Looking once again at the first sub-table in Table 9, the column for the 30 year-old says that the probability of no injury in this crash scenario is 0.46 (46 percent). However, the most likely outcome is a minor injury, which has an estimated probability of 0.48. For the 70 year-old occupant, the probability of no injury drops to 0.22. Instead, the probability of injury at all levels increases. The probability of an injury rated moderate or more severe rises from about 0.07 for the 30 year-old to 0.19 for the 70 year-old.

**Table 10.**
**Predicted Probabilities of Maximum Injury Severity to Car Occupants by Age, Delta-V, and Other Vehicle Type in Non-Rollover Two-Light Vehicle Nearside Crashes (NASS-CDS 1997 to 2001)**

| Probability of Maximum AIS | 30 year old | 55 year old | 70 year old |
|---|---|---|---|
| | (prediction for female) | | |
| Total Delta-V of 25 KMPH (other vehicle car) | | | |
| None (0) | 0.26 | 0.20 | 0.15 |
| Minor (1) | 0.61 | 0.62 | 0.62 |
| Moderate (2) | 0.07 | 0.09 | 0.11 |
| Serious (3) | 0.05 | 0.07 | 0.09 |
| Severe (4+) | 0.01 | 0.02 | 0.04 |
| Total Delta-V of 35 KMPH (other vehicle car) | | | |
| None (0) | 0.12 | 0.05 | 0.02 |
| Minor (1) | 0.60 | 0.51 | 0.38 |
| Moderate (2) | 0.12 | 0.16 | 0.17 |
| Serious (3) | 0.11 | 0.17 | 0.23 |
| Severe (4+) | 0.05 | 0.10 | 0.20 |
| Total Delta-V of 35 KMPH (other vehicle LTV) | | | |
| None (0) | 0.08 | 0.03 | 0.01 |
| Minor (1) | 0.56 | 0.44 | 0.30 |
| Moderate (2) | 0.15 | 0.17 | 0.16 |
| Serious (3) | 0.14 | 0.21 | 0.25 |
| Severe (4+) | 0.08 | 0.16 | 0.27 |
| Total Delta-V of 45 KMPH (other vehicle car) | | | |
| None (0) | 0.04 | 0.01 | 0.00 |
| Minor (1) | 0.48 | 0.27 | 0.11 |
| Moderate (2) | 0.16 | 0.16 | 0.10 |
| Serious (3) | 0.19 | 0.25 | 0.23 |
| Severe (4+) | 0.13 | 0.31 | 0.55 |

Table 9 indicates that in the relevant frontal crashes, both delta-V and age have an effect on the occupant's maximum known AIS. However, the largest effect occurs in crashes involving a relatively low delta-V. Frontal crashes at a delta-V of 50 KMPH look similar for the three ages in that they are likely to produce injuries at a moderate or higher level. This result is different from that found in Table 10. In Table 10, the effect of age is strong at all three levels of delta-V, but it becomes stronger as delta-V increases. The biggest effect of age can be seen when delta-V equals 45 KMPH. In this case, the probability of a serious or higher injury is 0.13 for the 30 year-old but 0.55 for the 70 year-old. Table 10 also shows the higher predicted injury when a car is struck in the side by an

LTV than by a car. The probability of minor injuries and less decreases and the probabilities of moderate or greater injuries increases when comparing the middle two sub-tables in Table 10.

**DISCUSSION**

Taking into account important factors for the safety of older occupants – growth in population, increasing travel exposure, crash involvement rates, and fragility – there are clear warning signs for the future safety of the oldest segment of the traveling public. This paper documents at least two important and related areas where the growth in the older population, their travel patterns and crash types could lead to substantial increases in target populations.

The first is that a significantly larger share of travel (in day trips) by the oldest occupants is by passenger car versus other types of vehicles. This passenger car concentration is also indicated by overall crash involvement rates. As discussed earlier, the fatality risk for passenger car drivers is greater than the risk for LTV drivers in two-vehicle frontal crashes. The fatality risk for car drivers struck in the side by an LTV is also substantially greater than the fatality risk for car drivers struck in the side by another car. These numbers are particularly meaningful for older occupants because they are more likely to crash with another light vehicle and less likely to be in single-vehicle crashes than younger occupants. Furthermore, this study shows that the predicted maximum injury level is higher for a car occupant struck by an LTV than another car even when controlling for age, gender, and delta-V. The small shift in the 75 and older group into vans from passenger cars would help to diminish this particular effect on target population projections, but a strong relationship between the percent of light vehicle miles traveled in car and the age of the occupant still exists.

The second factor is the importance of crash mode, particularly side impact crashes, in explaining injuries for older occupants. Side impact crashes, both from a crash involvement and survivability standpoint, are of the greatest concern. The review of previous literature suggested that older drivers are more likely to be involved in side impact crashes than younger drivers, and Table 4 demonstrated that older occupants are more likely to be in side impact crashes than younger occupants. For those 25 to 44, struck side impact crashes account for 11 percent of occupants involved in crashes, 7 percent of occupant fatalities, and 14 percent of seriously injured occupants. For those aged 75 and above, struck side impact crashes increase to 20 percent of occupants involved in crashes, 27 percent of fatalities, and 28 percent of those seriously injured. The increase in crash involvement explains some of the increase in the proportion of fatalities and serious injuries in struck side impact crashes, but survivability and frailty also play an important role. The results presented in this paper demonstrate that the expected maximum injury severity in side impact crashes where the car is struck on the occupant's side of the vehicle increases greatly with age, especially in crashes involving relatively high values of delta-V. This effect holds even when controlling for whether the other vehicle is an LTV.

Although not as important as side impact crashes, frontal crashes also play a role in explaining age differences. Involvement in two light-vehicle frontal crashes increases slightly with age, and the proportion of serious injuries from frontal crashes is about the same across age groups. However, the proportion of fatalities from frontal crashes increases substantially with age. Because there is little change in crash exposure, the explanation could be one of frailty. This argument is supported by the ordered probit results where the probability of a maximum AIS of 4 or greater increases with age, but age still does not have as strong an effect as it does in side impact crashes.

Increases in the population and vehicle travel by older occupants could exacerbate the compatibility problem related to the vehicle mix on the road since travel and crash involvement of the oldest population occurs disproportionately in passenger cars compared to younger age groups. In frontal impact crashes, the fact that older occupants are more likely to be in cars than LTVs increases their fatality risk. Several factors work together to increase the compatibility problem for older drivers in side impact crashes. The increase in older drivers will likely lead to an increase in side impact collisions. Also, the fact that older occupants involved in a side impact collision are more likely than younger occupants to be in struck cars, particularly cars struck by LTVs, increases the fatality and injury risk for older occupants. The results further suggest that problem is best addressed in terms of both crash avoidance and crashworthiness countermeasures.

Interestingly, an increase in the proportion of miles traveled by older occupants compared to younger occupants also suggests that some issues may not be as important in the future. For example, a larger proportion of older occupants would probably result in a smaller proportion of miles traveled by motorcycle. It also appears that single-vehicle rollovers diminish in importance as a cause of fatalities and incapacitating injuries as age increases. Therefore, a larger proportion of miles traveled by older occupants could result in fewer rollover fatalities and injuries per mile traveled. Also, as more older individuals move from pedestrians to vehicle occupants, pedestrian fatalities among the oldest population may fall. This change may help explain why total pedestrian fatalities decreased among those aged 70 and above between 1991 and 2001 even though the population increased substantially [15].

## CONCLUSIONS

Based on the results of this analysis, vehicle safety issues for the oldest segment of the population should be carefully examined over the next several years. While occupant protection in crashes presents significant challenges due to physiological issues in the oldest population and crash dynamics, solutions can be sought to ameliorate the damage they will sustain in a crash. These could include new safety belt technologies as well as increased side impact occupant protection. These results also echo the concerns of researchers regarding the crash compatibility of vehicles on the road and show that increased attention to vehicle engagement in side impact crashes would be particularly helpful for older occupants. Shifts in the proportion of the population by age will be an increasingly important determinate of future benefits for analyses of changes in vehicle safety standards. A greater body of research also is needed on vehicle technologies that can help older drivers avoid collisions. Research aimed at crash avoidance while making turns and while navigating intersections would help older occupants by reducing side impact crashes.

While programs aimed at reducing driving exposure should be continued and strengthened, it is likely that the oldest population will continue to have an expectation and level of mobility that is different from their parents and grandparents. Furthermore, this paper demonstrates that the issues involve non-drivers as well as drivers because growth will continue in older passenger exposure even if all driving ended. As a result, greater attention to vehicle safety issues, as well as behavior change, is needed.

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## APPENDIX

**Table 11.**
**Complete Order Probit Results**
**for Predicting AIS Injury Severity**

| Variable | Coefficient | Standard Error | Pr > Chi-Square |
|---|---|---|---|
| **Frontal Crashes** | | | |
| Intercept 1 | -1.8884 | 0.1912 | <.0001 |
| Intercept 2 | -1.6279 | 0.0496 | <.0001 |
| Intercept 3 | -2.1709 | 0.0620 | <.0001 |
| Intercept 4 | -2.8618 | 0.0893 | <.0001 |
| Age | 0.0248 | 0.0034 | <.0001 |
| Sex (0=male, 1=female) | 0.5290 | 0.0592 | <.0001 |
| Delta-V | 0.0666 | 0.0066 | <.0001 |
| Belt Use (0=no, 1=yes) | -0.3462 | 0.0680 | <.0001 |
| Age * Delta-V | -0.0004 | 0.0001 | 0.0002 |
| N=1,648 | | | |
| **Nearside Impact** | | | |
| Intercept 1 | -0.3473 | 0.2142 | 0.1049 |
| Intercept 2 | -1.7691 | 0.0610 | <.0001 |
| Intercept 3 | -2.1972 | 0.0759 | <.0001 |
| Intercept 4 | -2.8549 | 0.1116 | <.0001 |
| Age | -0.0165 | 0.0047 | 0.0004 |
| Sex (0=male, 1=female) | 0.1310 | 0.0639 | 0.0404 |
| Delta-V | 0.0221 | 0.0107 | 0.0380 |
| Striking Vehicle LTV (0=no, 1=yes) | 0.2418 | 0.0705 | 0.0006 |
| Age * Delta-V | 0.0011 | 0.0002 | <.0001 |
| N=1,350 | | | |